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ENGINEERING DESIGN FILE

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EDF No.: 5727   EDF Rev. No.: 0   Project File No.: 22901

1. Title: Corrosion Evaluation for Stainless Steel V-Tanks

2. Index Codes:
   Building/Type TSF-09/-18 SSC ID V-1, V-2, and V-3 Site Area TAN and ICDF

3. NPH Performance Category: ______ or X N/A

4. EDF Safety Category: ______ or ☒ N/A SCC Safety Category: CG or ☐ N/A

5. Summary:

The V-Tanks are scheduled to be placed in the ICDF landfill. This Engineering Design File provides a corrosion evaluation for these tanks. The stainless steel V-Tanks will experience extremely slow general corrosion from the outside soil conditions and the inside conditions. The general corrosion will only remove a very small fraction of the wall thickness. The V-tanks should remain structurally sound over 10,000 years, but there is a chance that there could be small local areas of pitting and cracking in areas of high tensile stress.

6. Review (R) and Approval (A) and Acceptance (Ac) Signatures:
   (See instructions for definitions of terms and significance of signatures.)

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Background
The V-Tanks V-1, V-2, and V-3 are scheduled to be placed in the ICDF landfill. This EDF provides a corrosion evaluation for these tanks and makes an estimate of the tanks condition after 10,000 years of exposure in the landfill. The landfill is lined with a polymeric sheet and equipped with a drainage system and will be capped with a polymeric sheet liner. The tanks are to be buried about 30 feet deep. The tanks will have an absorbent placed in them to absorb any free liquid; there will be no free liquid in the tanks. Grout will be poured on top of the absorbent to fill the void space.

Purpose and Scope
The objective of this evaluation is to estimate the condition of the stainless steel V-tanks V-1, V-2, and V-3 after 10,000 years exposure in the ICDF landfill.

Acceptance Criteria
The stainless steel tanks will be considered acceptable if the structural integrity of the tanks is maintained so that they do not collapse over time from corrosion and release the solidified material.

Analysis and Assumptions
Tank Material

The only information that is available regarding the tank material is that it is stainless steel. The most likely alloy would be a Type 304 stainless and is the basic assumption for this evaluation. Since the tanks were installed in the 1950's there is a chance that the stainless steel is not low carbon (i.e., 304L). This would mean that the areas immediately adjacent to the welds (the heat-affected-zones) could be marginally sensitized and therefore more prone to localized corrosion.

Metallurgical Condition

The tanks are most likely in the as-welded condition. Stainless steel is rarely stress relieved after welding.

Original Wall Thickness

The original wall thickness is not known, but the ultrasonically measured wall thickness for Tanks V-1, V-2, and V-3 are all over 0.5 inches.

Temperature

The tanks are to be buried 30 feet underground. A reasonable estimate of the temperature would be about 50 ^{o}F. The temperature of the underground Dry Well steel tanks at INTEC, buried 20 feet, only varies from 46 to 50 ^{o}F. This low temperature reduces the corrosion potential (e.g., damage) to the tanks.

Solution Composition

Corrosion of the V-tanks at ICDF will proceed from the outside in and from the inside out. These corrosion environments are considered separately. The grout to be placed inside the tank to fill the void space will have minimal effect upon corrosion.

Soil Conditions

Due to the ICDF landfill liner, cap, and drainage system, a low soil moisture content is expected.

External Corrosion Conditions

The moisture in the soil will cause extremely slow general corrosion of the tank walls. Stainless steel coupons that were buried four and ten feet deep for six years at RWMC showed little general corrosion. The coupons were made of 304L and 316L. After six years, the coupons are just starting to show a measurable weight loss (e.g., > 0.05 wt%). None of the coupons are experiencing pitting or cracking. (Figures 1 and 2)

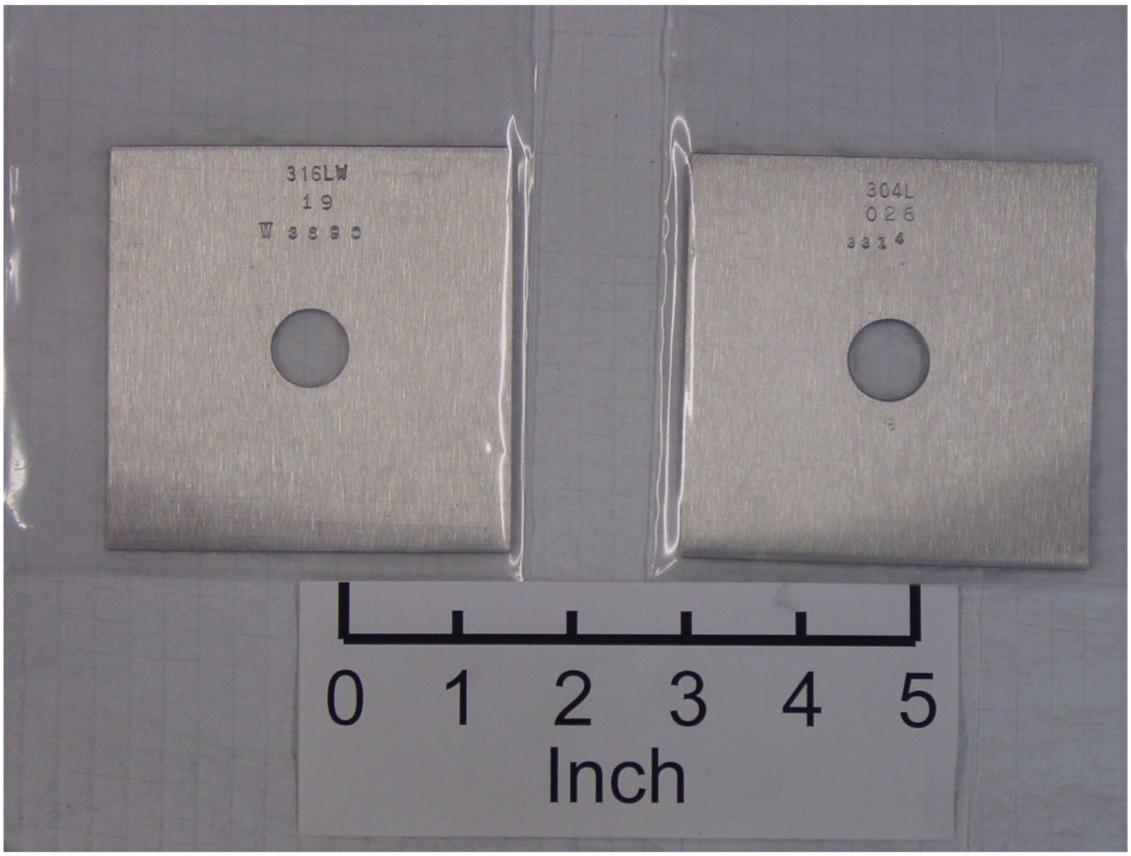

Figure 1. Typical 316L and 304L stainless steel corrosion coupons after six years exposure at RWMC (These coupons were buried four feet deep).

The RWMC measured corrosion rates are listed in Table 1. Even under the most conservative estimates, the depth of penetration caused from these predicted external corrosion conditions will only be a fraction of the wall thickness of the V-tanks (barring any climatic changes).

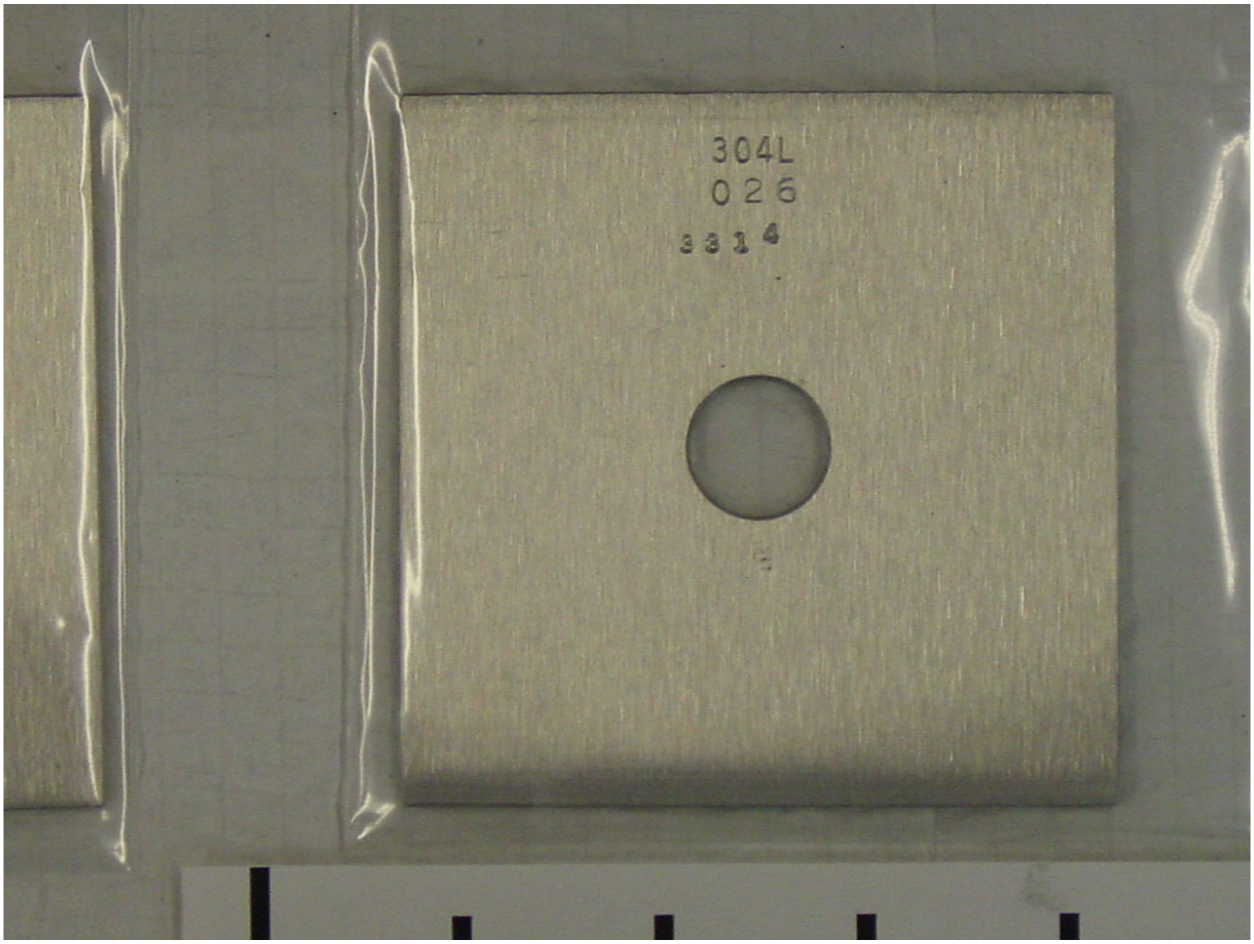

Figure 2. Closer view of 304L stainless steel coupon that was buried four feet deep for six years at RWMC.

Corrosion coupons were recently excavated after having been buried for at a saturated East Coast environment. These coupons had been buried for 34 years in New Jersey. These data are still being compiled; however, the coupons give a good indication of possible localized corrosion conditions if Eastern Idaho ever experiences a wetter climate. These coupons indicate that localized corrosion is possible and pitting and cracking could occur. However, the nature of localized corrosion means that structurally the tank would be adequate for 10,000 yr, but there could be a breach in the vessel wall. The following photographs document the type of coupon environment and their condition. One coupon shown was severely sensitized (2 hr at 650 ^{o}C) before burial making the alloy more prone to cracking and pitting. The only place on the V-tanks that would have any sensitization would be in the heat-affected zone next to the weld (if the tanks are 304 and not 304L stainless steel). However, the heat-affected zone would only have been in the sensitization temperature range (about 500 to 900 ^{o}C) for a short time during welding. The other coupon was in the solution-annealed condition. This is the condition for all other areas of the V-Tanks. These results indicated that even in the solution annealed condition there is a chance for through wall cracks and pits if Eastern Idaho's climate becomes wetter or the local ground water chemistry becomes more corrosive.

Table 1

Calculated Stainless Steel Corrosion Rates After Six Years of Underground Exposure

Coupon Number	Alloy	Depth (feet)	Weight Loss (grams)	Corrosion Rate (mils per yr [mpy])	Estimated Wall Thinning after 10,000 years (10^{-3} inches)
4 Foot Level Coupons					
3380	316L	4	.0017	.00011	1.1
W3688	316L welded	4	.0008	.00005	0.5
3381	316L	4	.0018	.00012	1.2
3320	304L	4	.0022	.00015	1.5
W3689	316L welded	4	.0009	.00006	0.6
3319	304L	4	.0008	.00005	0.5
3313	304L	4	.0010	.00007	0.7
W3690	316L welded	4	.0004	.00003	0.3
3382	316L	4	.0016	.00011	1.1
3384	316L	4	.0010	.00007	0.7
3314	304L	4	.0022	.00015	1.5
W3691	316L welded	4	.0009	.00006	0.6
10 Foot Level Coupons					
3315	304L	10	0	0	0.0
W3692	316L welded	10	.0008	.00005	0.5
3383	316L	10	.0012	.00008	0.8
3386	316L	10	.0015	.0001	1.0
W3693	316L welded	10	.0007	.00005	0.5
3385	316L	10	.0010	.00007	0.7
3316	304L	10	.0006	.00004	0.4
3387	316L	10	.0014	.00009	0.9
W3694	316L welded	10	.0009	.00006	0.6
3308	304L	10	.0017	.00011	1.1
3310	304L	10	.0011	.00007	0.7
W3695	316L welded	10	.0006	.00004	0.4

Figure 3. Buried coupon site prior to coupon removal. The coupons were buried two feet deep and there was considerable vegetation that had to be removed. Coupons were buried under the posts.

Figure 4. Coupon site after partial excavation. The water table was near the surface. As soon as digging commenced water was encountered.

Figure 5. Coupon removal in progress

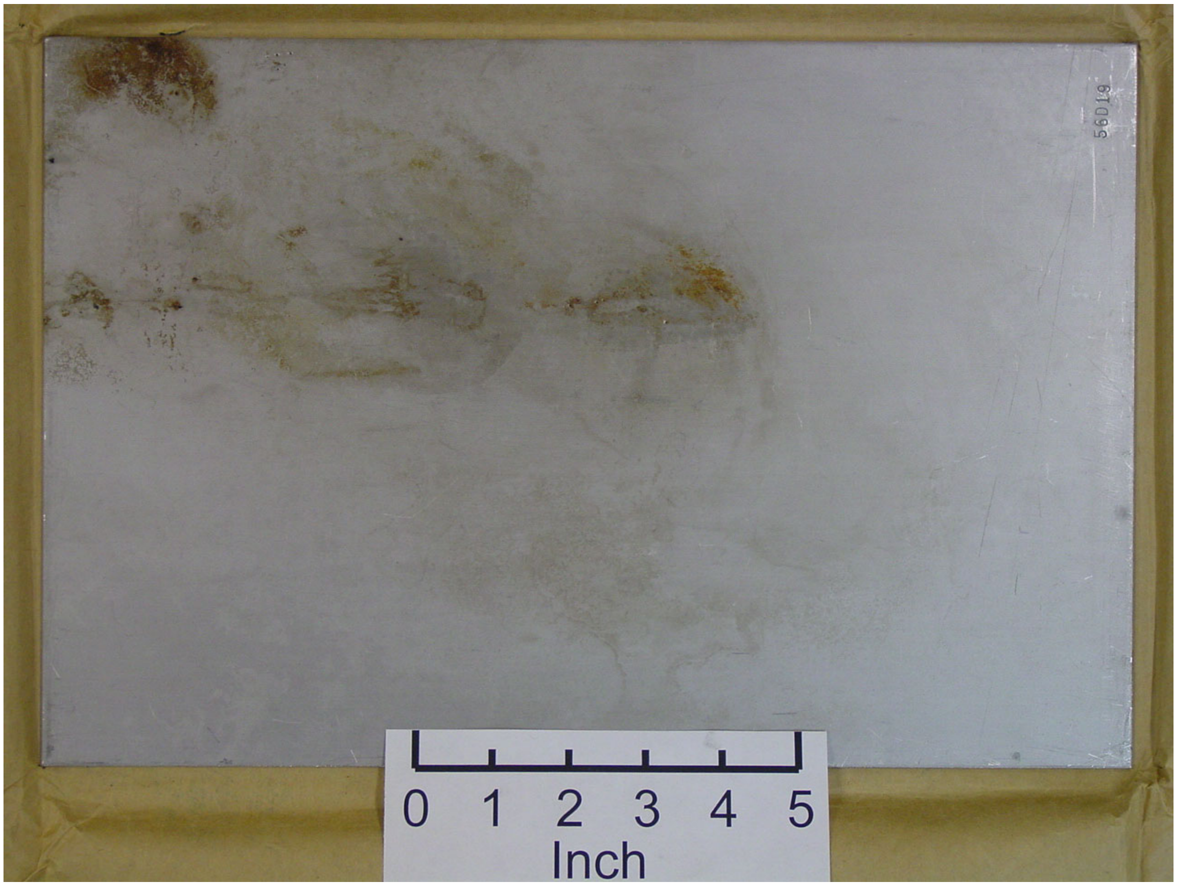

Figure 6. Type 304 stainless steel coupon after removal from wet soil after 34 years. The coupon had been sensitized for 2 hours at 650 ^{o}C. Heating the coupon to this temperature causes the microstructure to become more prone to pitting and cracking. This is an extremely severe condition not found in the V-tanks.

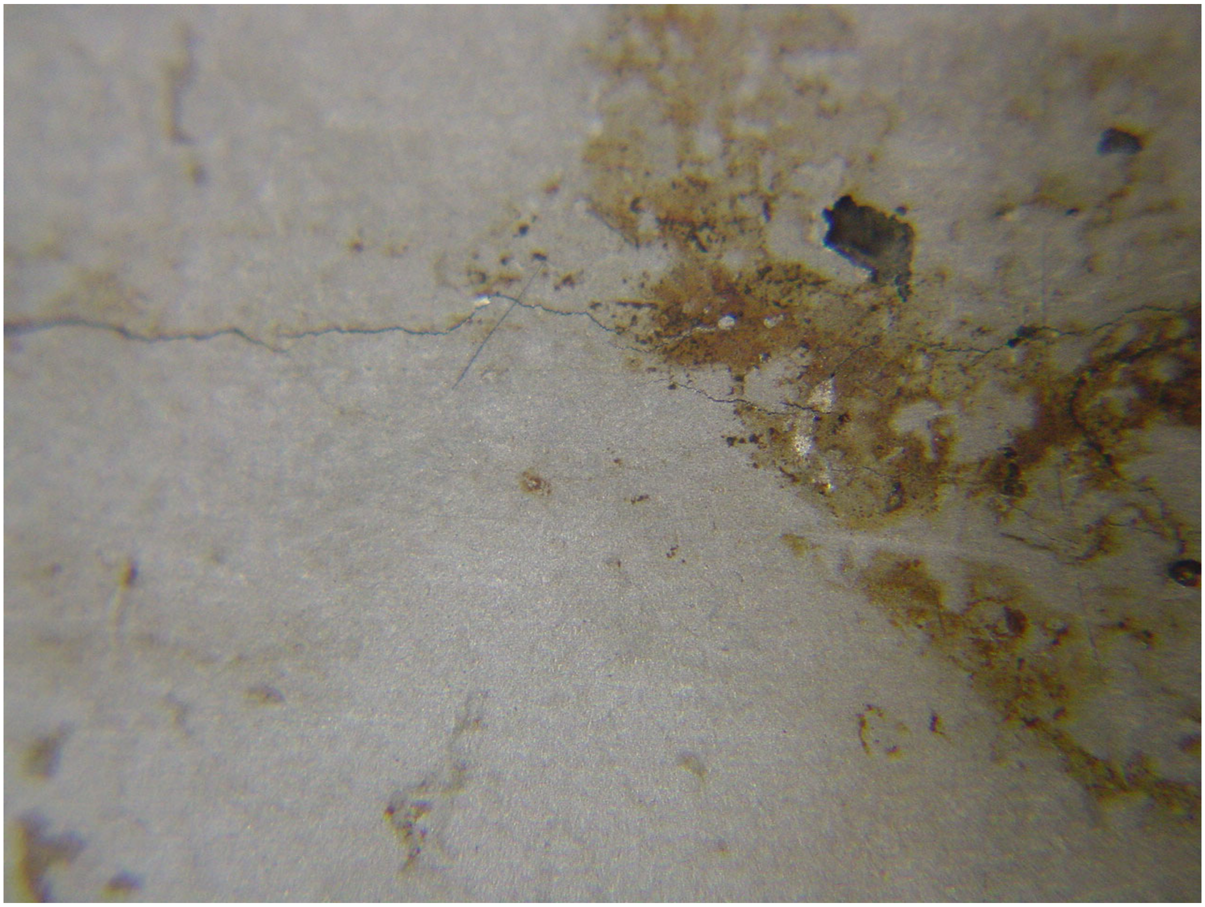

Figure 7. Closer view of localized corrosion of coupon in Figure 6 showing pits and cracks.

Figure 8. Solution annealed 304 stainless steel coupon after 34 years exposure underground.

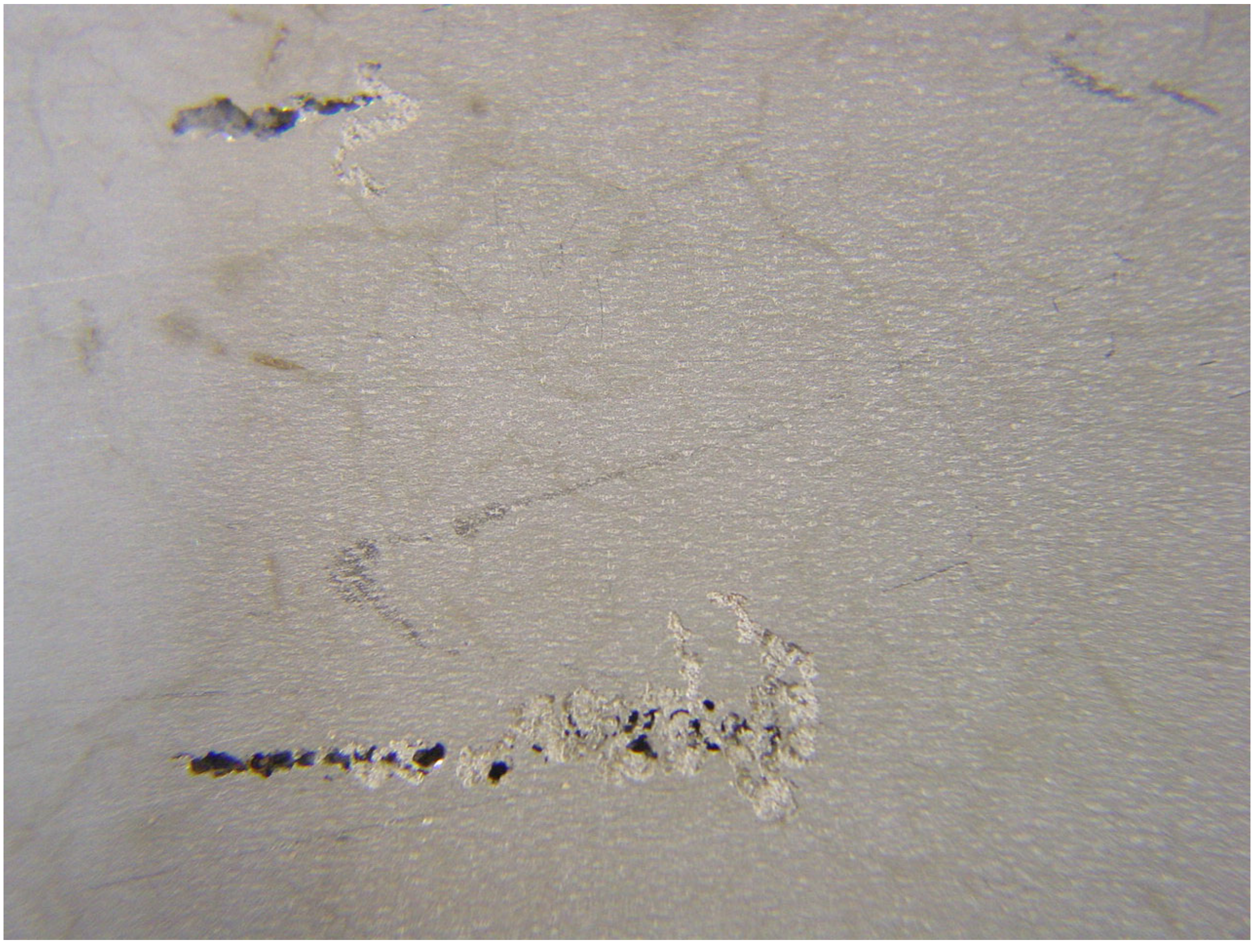

Figure 9. Close up view of pits in the solution-annealed 304 stainless steel sample.

V Tanks Internal Corrosion Conditions

The liquid inside the vessels consists of mostly water with some radionuclides, ions, and trace amounts of organics[1,2]. Chloride concentration and pH are critical components for corrosion of stainless steel. The chloride concentration is only about 100 mg/L and the pH is about 8. These are favorable conditions to avoid cracking especially with the low ambient temperature. Prior to burial, the liquid will be absorbed using a polymer so that there is no free liquid. Without liquid (an electrolyte) corrosion does not occur. However, there could still be moist air inside the tank with local corrosion cells and there is a chance that the polymer absorbent could break down over the years and release liquid. If this ever happens the corrosiveness of the solution would be low. Corrosion from this type of solution (neutral pH and low chloride concentration) could cause pitting and cracking over extended times especially in areas of higher tensile stress. However, the general corrosion rate would be very low and the tank would still have structural integrity for 10,000 yr. Consequently, the corrosion mechanism (localized corrosion) inside the tanks would be similar to that on the outside.

Effect of Stress

Tensile stresses promote localized corrosion such as cracking. The stresses associated with the V-tanks include residual stresses from fabrication and applied stresses from being buried underground. Depending on orientations, these applied stresses could be additive to the residual stresses. The estimated maximum stresses from the soil loads are about 20 ksi.[3]

The residual stresses caused from welding can be significant and approach the yield strength of the alloy and encourage cracking. Table 2 shows the effect of stress on the time to failure for 304L tensile samples. These samples were stressed to a fraction of the Ultimate Tensile Strength. The samples should have never broken, but since they were exposed to mixture of chloride salts, the samples cracked. Note that as the stress decreased the time to failure increased. Also to be noted is that the test temperature is 40ºC, which is much higher than the expected temperatures of the V-tank (4.5ºC or 40ºF). Therefore, this environment is far more aggressive than anything that will be encountered at ICDF, but illustrates the effect of stress.

Table 2

Effect of Stress on Cracking of 304L Stainless Steel

Stress (ksi)	Percent of Ultimate Tensile Strength	Time to Failure (hrs)	Temp (C)
80	76	33	40
60	57	153	40
40	38	247	40
20	19	303	40

Figure 10 shows a finite element analysis model of a longitudinal weld for a 304 stainless steel vessel. For these tests the wall thickness was only 0.125 in. thick and the diameter was six inches. The model indicated significant tensile stresses (35 to 45 ksi) in the welds and the heat-affected zone. The areas of red and orange in Figure 10 are the areas of significant tensile stresses. Similar stresses would have occurred when the V-tanks were fabricated. A chloride salt was placed on the outside surface of these stainless steel coupons and kept at 104ºF (40 ^{o}C) and 40% relative humidity. Figure 11 shows the stainless steel coupon prior to exposure to the chloride salts. Chlorides are known to cause stress cracking and pitting of type 304 stainless steel. Cracks were visible to the naked eye when the coupon was inspected after four months (Figure 12). The cracks were in the heat-affected zone.

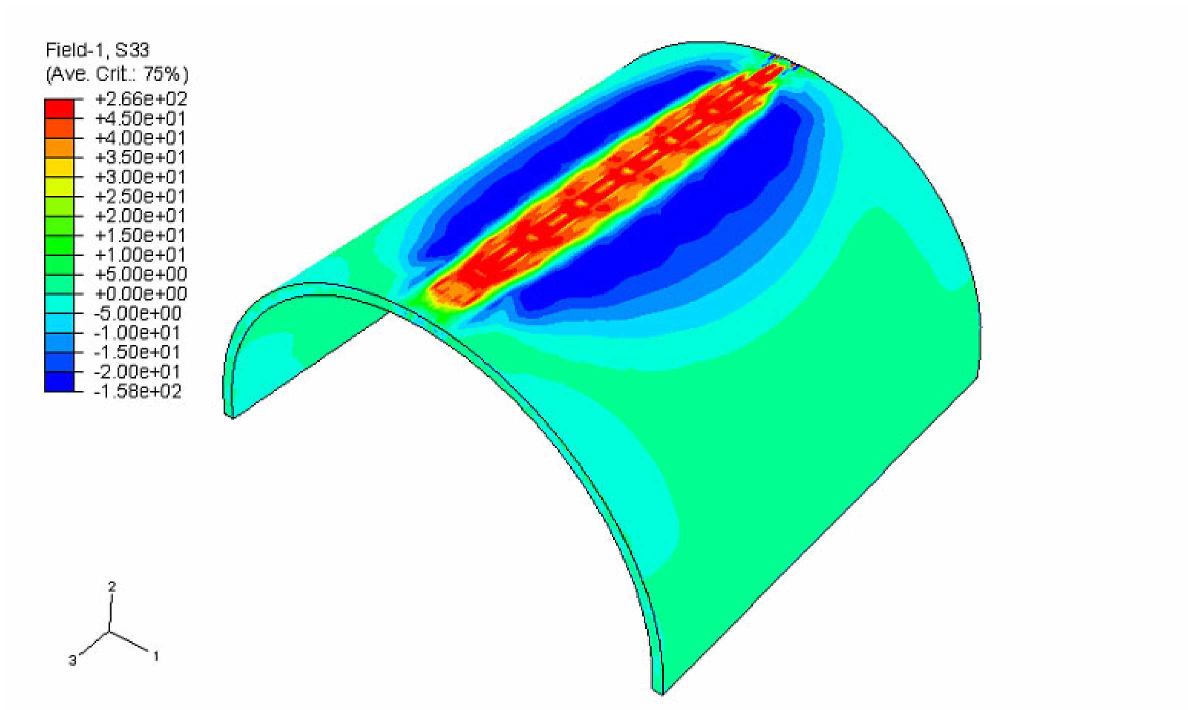

Figure 10. Calculated residual stresses from welding. The stresses in the weld and heat-affected zone are estimated to be around 35 to 45 ksi.

Figure 11. Welded 304 stainless steel coupon prior to exposure to chloride salts at 40 ^{o}C and 40% relative humidity

Figure 12. Close-up view of weld and heat-affected zone after 120 days exposure to chloride salts. Cracks are visible in the dark areas.

Conclusions
The stainless steel V-Tanks (assumed as 304) will experience extremely slow general corrosion from the outside soil conditions and the inside conditions. The general corrosion will only remove a very small fraction of the wall thickness.

The V-tanks should remain structurally sound over 10,000 years, but there is a chance that there could be small local areas of pitting and cracking in areas of high tensile stress.

Technical Checking Method
Detailed document review.

References

1. EDF 3868, V-Tank Analytical Data – Calculated Averages and Upper Confidence Limits, December 2003.
2. EDF-4928, Potential Feed Streams for Inclusion Into V-Tank Treatment Process, March 2005.
3. EDF-5595, TSF-09/18 V-Tanks Remediation Tank Lift Lug Design, April 2005.